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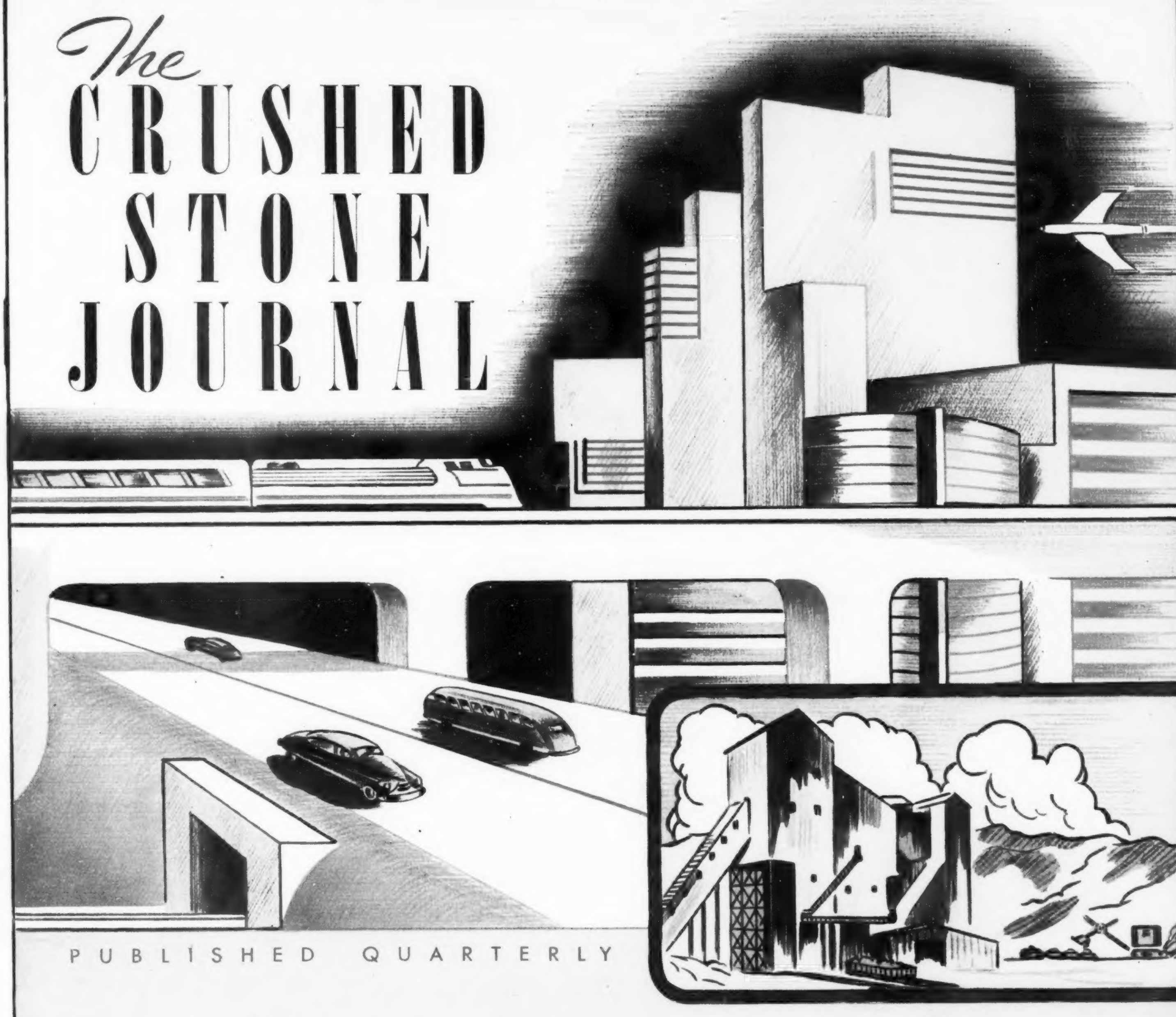

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June 1950

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The Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

J. R. BOYD, Editor

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Week of February 5, 1951

NETHERLAND PLAZA, CINCINNATI, OHIO

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The Identification of Rock Types*

By The Physical Research Branch
Bureau of Public Roads

Reported by D. O. WOOLF
Senior Materials Engineer

• Sufficient familiarity with the characteristics of rocks to identify them, even approximately, should be valuable to stone producers. The following article describes the controlling features of different rock types and indicates how to recognize them.

THE method of identification of rock presented here is intended to be applied to pieces of a size large enough so that the structure of the rock can be observed clearly. In small pieces, the alinement, if any, of the minerals composing the rock may not be observed as readily as it would be in a larger piece. The user of this method is urged to obtain for study as large a piece of the rock as is convenient to handle. Pieces about 3 in. by 4 in. by 2 in. thick may be found to be suitable.

The equipment needed consists only of a knife blade of good steel, a small magnifying glass of 6 to 10 power, and a bottle of dilute hydrochloric acid, preferably with a dropper. If the acid is not available, household vinegar will usually serve in its place. Sometimes a fragment of quartz or a quartz crystal may be found useful, but generally crystals which are large enough to test with the quartz can be identified visually.

This method follows that given by Pirrson and Knopf,[1] which in turn was based on that given by Geikie in his Textbook of Geology.[2] It uses a combination of simple physical and chemical determinations to identify the rock. In some cases the individual minerals can be identified, and the rock can be named from a knowledge of its component minerals, their abundance, and the relative amounts of each.

TABLE I
General Classification of Rock

Class	Type	Family
Igneous	Intrusive (coarse-grained)	Granite [1] Syenite [1] Diorite [1] Gabbro Peridotite Pyroxenite Hornblendite
	Extrusive (fine-grained)	Obsidian Pumice Tuff Rhyolite [1,2] Trachyte [1,2] Andesite [1,2] Basalt [1] Diabase
Sedimentary	Calcareous	Limestone Dolomite
	Siliceous	Shale Sandstone Chert Conglomerate [3] Breccia [3]
Metamorphic	Foliated	Gneiss Schist Amphibolite Slate
	Nonfoliated	Quartzite Marble Serpentinite

[1] Frequently occurs as a porphyritic rock.
[2] Included in general term "felsite" when constituent minerals cannot be determined quantitatively.
[3] May also be composed partially or entirely of calcareous materials.

* Reprinted from *Public Roads*, June 1950, published by Bureau of Public Roads, U. S. Department of Commerce, Washington, D. C.
[1] *Rocks and Rock Minerals*, by Louis V. Pirrson and Adolph Knopf, 3rd edition; John Wiley and Sons, Inc., New York; 1947.
[2] *Textbook of Geology*, by Sir Archibald Geikie, 3rd edition; MacMillan and Co., London; 1893.

In other cases the minerals may be too small to identify with the hand lens, and recourse must be had to the general distribution of the minerals and to the structure of the rock. It should not be expected that this method will permit the identification of any and all rocks, but it is believed that the user will be able to identify the more common rocks used in highway construction. In those cases where the rock cannot positively be identified, the user of this method should have no hesitancy in stating which type of rock the sample under study most closely resembles, and describing the particular features of the sample which are not in agreement with the characteristics of the type mentioned.

General Classification

A general classification of rocks of interest in highway construction is given in Table I.[3] The rocks are first separated into three classes—igneous, sedimentary, and metamorphic—on the basis of their origin, and each class is subdivided with regard to physical characteristics or chemical composition.

In the igneous class, the intrusive or coarse-grained rocks include such familiar materials as granite and gabbro. These rocks were formed from molten material and cooled slowly so that the crystals composing the rock developed to an appreciable size. The extrusive rocks were also formed from molten material, but these cooled so rapidly that the crystals are very small. In a few cases, the molten material formed as a glass, resulting in obsidian or similar rocks. The fine-grained crystalline rocks include rhyolite, trachyte, andesite, basalt, and diabase. The first three of these rocks are sometimes grouped under a general family name of felsite which includes light- to medium-colored, very fine-grained igneous rocks. Basalt and diabase are frequently described in engineering terminology as "trap" rock.

The sedimentary class of rocks, formed by deposition of water- or wind-transported rock grains, is separated into two groups on the basis of the principal mineral component. The calcareous rocks, which are composed essentially of compounds of lime or magnesia, include limestone and dolomite. Sedimentary rocks, which are composed chiefly of silica, include shale, sandstone, and chert.

[3] Based on table 2 in *Relation of Mineral Composition and Rock Structure to the Physical Properties of Road Materials*, by E. C. E. Lord; U. S. Department of Agriculture Bulletin No. 348; April 4, 1916.

The metamorphic class is separated into two groups based on the structure of the rock. In the foliated or layered types are included gneiss, schist, and slate, while quartzite and marble are included in the nonfoliated type. The metamorphic class includes those rocks which have been formed from another type of rock by heat or pressure. For example, gneiss may be formed from granite, marble from limestone or dolomite, and quartzite from sandstone. Sometimes this alteration improves the quality of the rock, as in the case of quartzite, which is a much harder and tougher material than sandstone. In other cases, the reverse applies: marble generally is inferior to limestone or dolomite as an aggregate for highway construction.

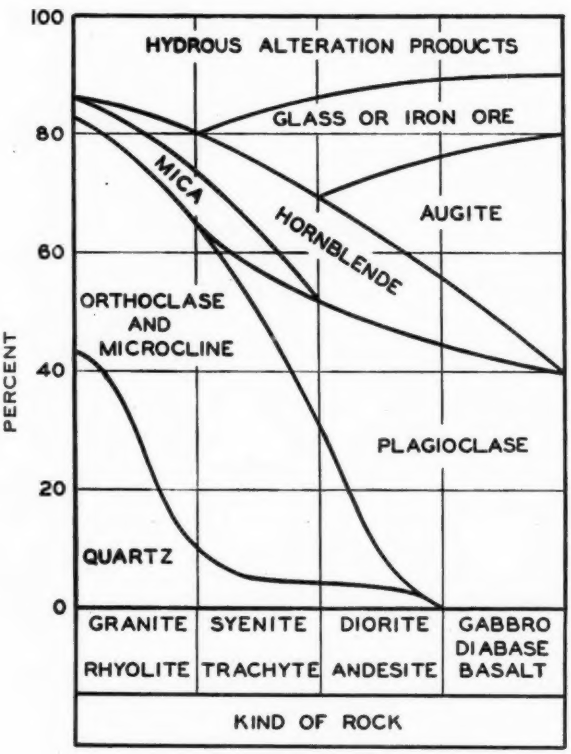

FIGURE 1
Diagrammatic Representation of the Mineral Composition of Igneous Rocks

Mineral Composition of Rocks

The more important rock-forming minerals are listed in Table II. These are separated into primary

and secondary minerals depending upon whether they are found in the original igneous rocks or were derived by alteration of the minerals in these rocks.

TABLE II
Rock-Forming Minerals

Primary minerals	
Name	**Composition**
Quartz	Silicon dioxide.
Feldspar:	
Orthoclase	Silicate of potassium and aluminum.
Microcline	Silicate of potassium and aluminum.
Plagioclase	Silicate of sodium, calcium, and aluminum.
Pyroxene:	
Augite	Silicate of calcium, iron, magnesium, and aluminum.
Amphibole:	
Hornblende	Complex silicate principally of calcium, iron, magnesium, and aluminum.
Mica:	
Muscovite	Hydrous silicate of potassium and aluminum.
Biotite	Hydrous silicate of potassium, magnesium, iron, and aluminum.
Magnetite	Iron oxide.
Rock glass	Variable.
Garnet	Silicate of aluminum, iron, and calcium.
Olivine	Silicate of magnesium and iron.
Secondary minerals	
Name	**Composition**
Calcite	Calcium carbonate.
Dolomite	Calcium and magnesium carbonate.
Kaolin	Hydrous silicate of aluminum.
Chlorite	Hydrous silicate of iron, magnesium, and aluminum.
Epidote	Hydrous silicate of calcium, aluminum, and iron.
Limonite	Hydrous iron oxide.
Opal	Hydrous silicon dioxide.

The essential mineral composition of the more common rocks used in highway construction is given in Table III. This is a condensation of material given in United States Department of Agriculture Bulletin No. 348.[4] In Table III, the average percentage distribution of the minerals which are characteristic of each variety of rock is shown, together with incidental minerals which are indicated by values in parentheses. Minerals which are present in the rocks in amounts less than 3 per cent are not mentioned separately but are grouped in the table under "remainder."

[4] See footnote 3, page 4.

In Figure 1, a graphical representation of the composition of igneous rocks is shown. This is based on the data given in Table III, but has been idealized to a certain extent for purposes of simplification. In the segment marked "glass or iron ore," the rock glass applies to the fine-grained extrusive rocks only.

The color of the rock furnishes some indication of the mineral content. If the rock is white or light in color, the predominant minerals probably are quartz and feldspar. Red, brown, green, gray, and black colors usually indicate the presence of minerals containing iron. In sedimentary rocks, gray or black colors may be caused by carbonaceous matter.

Classification by Geologic Type

It will be helpful if the user can classify rock with respect to its general geologic type, that is, whether the rock was formed directly from a molten mass (igneous class), or was formed by deposition of the rock grains transported by water or wind (sedimentary class) or was formed by the action of heat or pressure or both on previously existing rock (metamorphic class). Features which will assist in this classification of rock are the following:

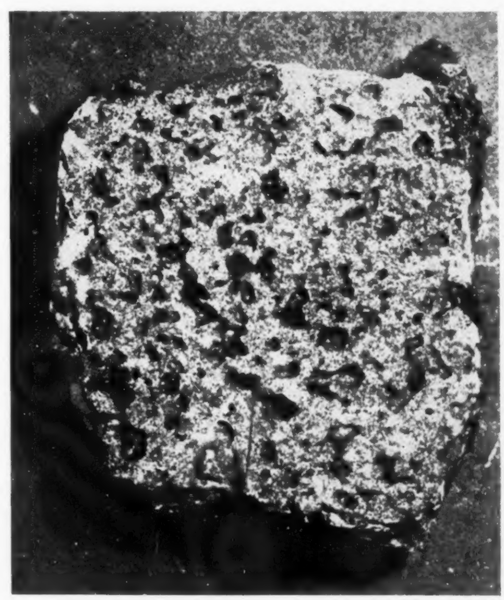

FIGURE 2
A Vesicular Basalt (Full Size)

TABLE III Mineral Composition of Rocks

Name of rock	Number of samples tested	Essential mineral composition, per cent[1]													
		Quartz	Orthoclase Microcline	Plagioclase	Augite	Hornblende	Mica	Calcite	Dolomite	Chlorite	Kaolin	Epidote	Iron ore	Rock glass	Remainder
Igneous rocks:															
Granite	165	30	45	(8)			6				(6)				5
Biotite granite	51	27	41	9			11				(7)				5
Hornblende granite	20	23	34	12		13	4				(10)				4
Augite syenite	23	(4)	52	7	8		4			(3)	(11)	(3)	(4)		4
Diorite	75	8	7	30		27	(4)			(3)	(8)	(5)	(3)		5
Gabbro	50			44	28	9				(3)	(6)				10
Rhyolite	43	32	45	(3)			(5)			(4)	(3)		(4)		4
Trachyte	6	(3)	42			6		(3)		(3)	(14)	(8)	(7)	9	5
Andesite	67			48	14	3				(6)		(3)	(8)	12	6
Basalt	70			36	35								(3)	21	5
Altered basalt	196			32	31					(9)	(4)		(4)	12	8
Diabase	29			44	46								(4)		6
Altered diabase	231			35	26					(15)	(9)		(4)		11
Sedimentary rocks:															
Limestone	875	(6)						83	8						3
Dolomite	331	(5)						11	82						2
Sandstone	109	79	(5)								(4)		(9)		3
Feldspathic sandstone	191	35	26					(3)		(3)	(22)		(4)		7
Calcareous sandstone	53	46	(3)					42					(3)		6
Chert	62	93													[2]7
Metamorphic rocks:															
Granite gneiss	107	37	35	(3)			18								7
Biotite gneiss	62	31	35	(5)			21								8
Hornblende gneiss	18	10	16	15	(3)	45	(4)								7
Mica schist	42	37	16				38								9
Biotite schist	17	34	13	(3)			41								9
Chlorite schist	23	11		10		(5)				39		28	(4)		3
Hornblende schist	68	10	(3)	12		61						(7)			7
Amphibolite	22	(3)		8		70						12			7
Slate	71	29	(4)				55						(5)		7
Quartzite	61	84	(3)				(4)								9
Feldspathic quartzite	22	46	27				(7)			(3)	(10)				7
Pyroxene quartzite	11	29	19	15	24								(5)		[3]8
Marble	61	(3)						96							1

[1] Values shown in parentheses indicate minerals other than those essential for the classification of the rock.
[2] Includes 3 per cent opal. [3] Includes 3 per cent garnet.

Igneous class:

- Absence of fossils.
- Presence of glass.
- Uniformity of structure.
- Interlocking crystals.

Sedimentary class:

- Rounded grains.
- Presence of fossils.
- Stratification in relatively thick layers.
- Abrupt changes in color from layer to layer.

Metamorphic class:

- Separation of crystals into approximately parallel layers.
- Formation in thin parallel layers.
- Broken readily into thin slabs.

All features mentioned for a given class probably will not be found in one single piece of rock, but one or more of those mentioned should be found.

Rock Structure

The structure of the rock is of considerable assistance in determining the general classification of the rock and also in determining the precise name for the material. Masses of rock which show a marked resemblance to columns are unquestionably of an igneous origin. Rock which is vesicular—that is, containing large or small cavities which sometimes are separated by thin walls of rock—is usually an igneous type. An example of this is shown in Figure 2. In some igneous rocks these cavities are filled with a material which is of a different nature from that of the rock itself, and the rock is said to have an amygdoloidal structure.

Most types of metamorphic rocks show a peculiarity of structure which is described as foliation. Such rocks could as well be described as banded or layered, except that these terms imply an abrupt change in the appearance of the rock from one layer to the next. Bands and layers are frequently used in descriptions of sedimentary rocks. Three types of foliation—gneissoid, schistose, and slaty—are used in descriptions of metamorphic rocks. All of the foliated rocks will split or cleave more or less readily in one plane, and the type of foliation describes the degree of smoothness of the cleaved surface. Rocks with a gneissoid foliation have a rough, uneven surface while those with a slaty foliation have a very smooth cleaved surface. Schists or rocks with a schistose foliation have cleaved surfaces which are much smoother than the gneisses but not as smooth as the slates.

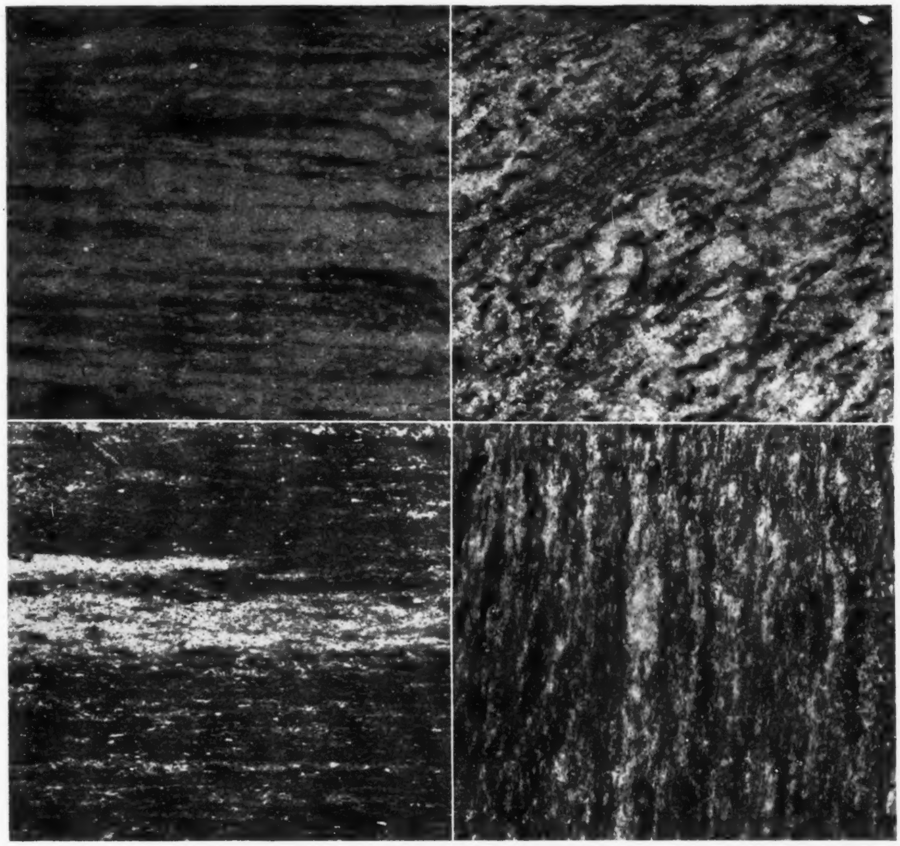

FIGURE 3

Typical Banding in Foliated Metamorphic Rocks: Granite Gneiss (Upper Left); Biotite Gneiss (Upper Right); Hornblende Schist (Lower Left); Mica Schist (Lower Right)

Under the effect of heat or pressure, the minerals in the foliated metamorphic rocks have been caused to arrange themselves in more or less parallel planes. The dark-colored minerals may separate from the light-colored minerals and form bands or streaks which are characteristic of certain foliated rocks. Figure 3 shows typical specimens of gneiss and schist. A close examination of such rocks will show that there is seldom an abrupt and complete separation between the dark- and light-colored minerals. Usually there is a zone of transition from light to dark bands, or the dark bands will contain an appreciable percentage of light-colored minerals. Banded sedimentary rocks which may be confused with the metamorphic rocks generally have an abrupt change in color or texture from one layer to the next, as shown in Figure 4.

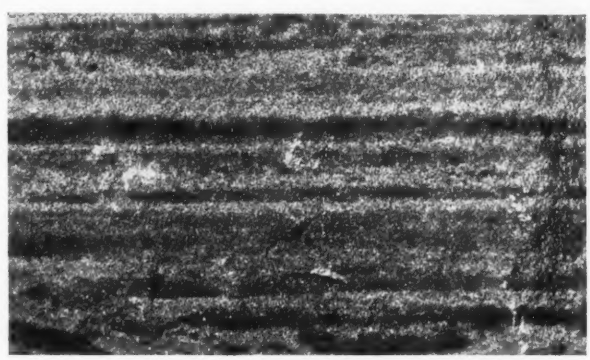

FIGURE 4

Abrupt Change in Color Between Layers Is Characteristic of Banded Sedimentary Rocks (Banded Sandstone)

Identification of Quartz and Feldspar

In the use of this method, it is necessary that quartz and feldspar be identified when these minerals occur in crystals or grains large enough to be seen with the aid of the hand lens. Their identification as constituents of rock may present some difficulties, since even in rocks of coarse grain these minerals may be so small that the usual determinations made on the ordinary mineral specimen frequently cannot be applied. For example, in hand specimens of minerals, feldspar may be identified in part by the fact that it is scratched by quartz. This test can seldom be applied to rock specimens due to the small size of the component crystals or grains. Recourse must be made to visual examination with reference to the color, shape, luster, and fracture of the grains.

In igneous rocks, quartz usually has a gray or smoky color, while feldspar is white, gray, or various shades of red. Grains of quartz are usually transparent or translucent, but those of feldspar are opaque. Quartz and feldspar are dissimilar in cleavage: if the grains are sufficiently large, those of feldspar will be found to break with flat surfaces forming an angle of about 90 degrees. By rotating the hand sample of rock so that light strikes the surface at different angles, the cleavage faces of feldspar crystals may be observed. A photograph showing the reflection of light from a cleavage face of a rather large crystal of feldspar in a specimen of granite is shown in Figure 5. Quartz has no cleavage, and breaks with a conchoidal or shell-like fracture. Quartz has a glassy luster while feldspar has a luster more nearly like porcelain. Feldspar is affected by weathering, and the luster tends to become dull.

In the crystallization of the rock minerals from the mass of molten rock, the feldspars crystallize before quartz, and tend to occur in crystal form while quartz develops in more or less shapeless masses. Feldspar crystals frequently are compound structures of intergrown crystals which developed simultaneously. The longitudinal axes of the portions of the crystals are parallel, but the transverse axes of one crystal segment are rotated through 180 degrees from those of the adjacent segment. At the junction between crystal segments, a plane of twinning is produced. In rock-making feldspars, these planes of twinning usually are very closely spaced, and the cleavage surface of a crystal of feldspar may appear to have been ruled with fine, parallel lines, as shown in Figure 6. This twinning is not found in quartz.

A summarization of the principal characteristics of feldspar and quartz as components of igneous rocks is shown in Table IV.

TABLE IV
Characteristics of Feldspar and Quartz as Components of Igneous Rocks

Characteristic	Feldspar	Quartz
Color	White, pink	Gray, smoky.
Transparency	Opaque	Translucent.
Luster	Porcelaneous to dull.	Glassy.
Cleavage	Good on two faces forming angles of about 90°.	None.
Form of crystal face.	Parallelopiped	Shapeless.
Multiple twinning.	Frequent	None.

Identification of Other Minerals

In some cases, the common forms of the ferromagnesian minerals augite, hornblende, olivine, and biotite may also be identified in rocks. The ferromagnesian minerals contain iron or magnesia or both as a principal component, and are identified by shape and color. In some rocks the minerals are sufficiently well crystallized for identification, but frequently they occur as grains or irregular masses and identification in the hand specimen may not be possible except by color.

Olivine is seldom found in well-developed crystals in rock. It occurs usually as grains or masses, and is identified by its color which varies from an olive green to a yellow green.

Augite and hornblende are the more common varieties of two large families of minerals, the pyroxenes and the amphiboles. Both augite and hornblende have a dark green to black color, and both frequently occur as grains or masses in rock. Identification of these minerals in the hand specimen depends upon whether the crystal shape can be determined. Augite tends to develop in short, thick crystals with a square or rectangular cross section. Hornblende commonly occurs as long, slender blades with irregular ends, and the cross section has a diamond shape with the acute angles replaced by parallel planes at right angles to the longer transverse axis of the crystal. Biotite is black mica, and is recognized by its black, shining color, its softness, and its occurrence as irregular flakes or scales in granites, syenites, and metamorphic rocks.

System for Rock Identification

The system for the identification of rock is shown in tabular form on page 11. In this method, all considerations are based on the appearance or character of newly fractured surfaces of the unweathered rock. In determinations of gravel, many pieces may be found to be weathered and some modifications of the characteristics mentioned may be expected. For example, pieces of feldspar in gravel may have a dull luster, and some pieces may be so soft that they can be scratched with the knife.

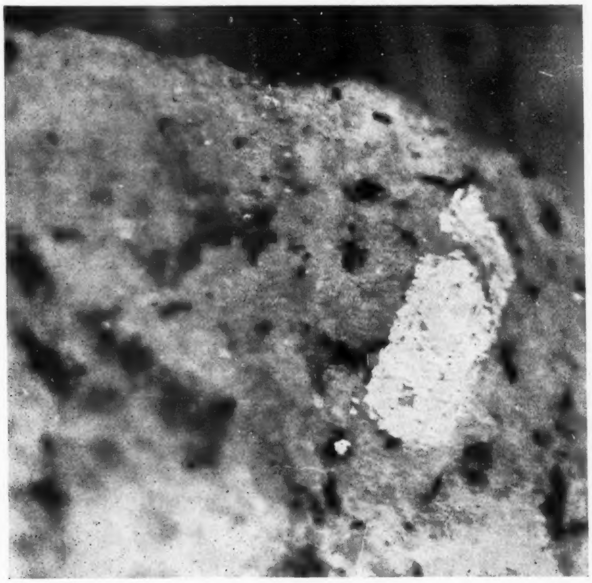

FIGURE 5
Reflection of Light From a Cleavage Face of a Feldspar Crystal in Granite (About 2X)

The first determination in the system is the preliminary classification by which the specimen is placed in one of five general groups.

When a determination of the lithological composition of a gravel is made, it is believed to be most desirable to separate the entire sample into the various general groups, and to examine each group of particles as an entity, subdividing each by the methods described. This should permit the identification to be performed most rapidly, and should group individual particles which show variations from a given class of rock due to slight differences in color, texture, or the effects of weathering.

In group I, glassy rocks, quartz is included as a rock. Actually this is not correct as quartz is a mineral, differing from rock in that it has a chemical composition expressible by a formula and also has a definite crystalline structure. However, quartz does occur in sufficiently large masses so that it is quarried as a rock, and is the most common material in a large percentage of gravels used for construction purposes. Due to these reasons quartz is included in the table.

Subgroup II B, covering hard, fine-grained rocks, contains some types of rock which lately have become of considerable interest to those concerned with the durability of portland cement concrete. Included in the general term "felsite" are a number of varieties of rock which may be chemically reactive to a detrimental degree with the alkali in cement. These include rhyolite, trachyte, and andesite. The identification of these rocks requires that both the kind and amount of feldspar present be determined. This determination cannot be made on the hand specimen, and the practice of grouping all fine-grained, light- or medium-colored, igneous rocks

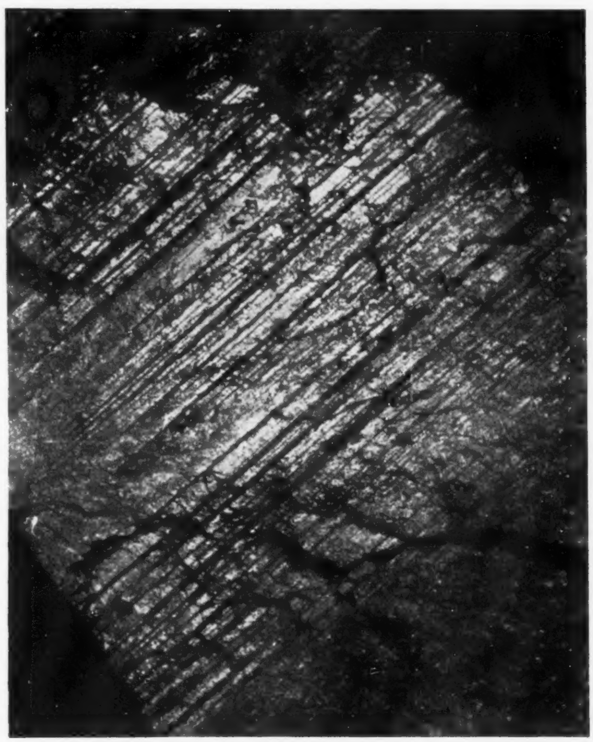

FIGURE 6
Planes of Twinning in Feldspar Produce an Appearance of Fine, Parallel Lines (About 3X)

containing feldspar as a major constituent under the general term of felsite has been adopted. This is believed to be a sound procedure, as the various rocks so grouped appear to have essentially the same properties from the engineering viewpoint.

In subgroup III B, item 5, separation between sandstone and quartzite is made by examination of the plane of fracture of the rock. If the fracture is around the grains of quartz, the rock is sandstone.

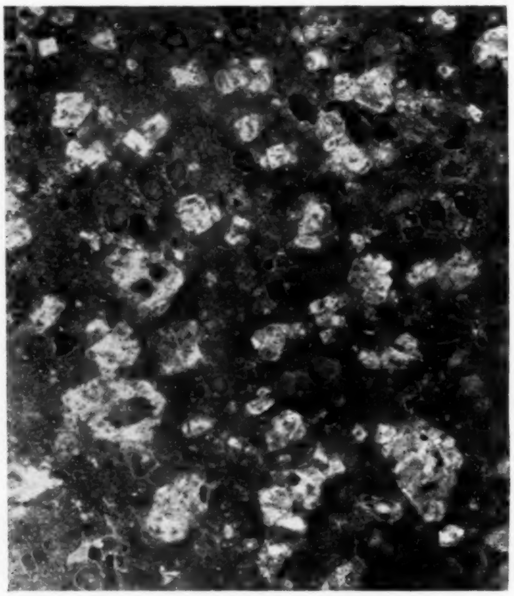

FIGURE 7
Porphyritic Granite (Full Size)

If the fracture passes through the grains, or through an appreciable percentage of the grains, the rock is quartzite.

Subgroup III C covers rocks of a porphyritic texture as shown in Figure 7. Originally, a porphyry referred to a rock composed of feldspar crystals embedded in a compact, dark red or purple groundmass. This name now refers to rocks containing large crystals of any kind, either well-formed or corroded to a rounded or irregular shape, which are embedded in a more finely crystalline or glassy groundmass of any color. A porphyry could refer to a rock containing crystals as big as an inch long which are embedded in a groundmass of crystals one-fourth inch in size; or it could refer to a rock containing crystals one-tenth of an inch in size embedded in a groundmass of barely visible crystals. In the laboratories of the Bureau of Public Roads, the name porphyry is used to refer to a rock containing numerous and more or less uniformly distributed crystals over one-eighth inch in size embedded in a groundmass so fine-grained that the individual grains are not recognized by the unaided eye.

Kemp[5] states that porphyries are commonly classified from the larger crystals (phenocrysts), with little regard for the composition of the groundmass even though the latter comprises over half of the rock. If the groundmass is of very fine grain, no other practice than that mentioned above can be followed without the use of the petrographic microscope or analysis by chemical methods.

In group IV, foliated rocks, it is doubted that the many varieties of schist can always be determined in the hand specimen. A few of the more common varieties are mentioned. There are many others, depending upon the presence of some mineral which may be in sufficient quantity or have certain unique properties to warrant its use as a modifier of the general term, schist. Most schists have about the same physical properties and the identification of the rock by this name alone may usually be sufficient.

In group IV, item 2(b), hornblende schists contain a small amount of quartz whereas amphibolites contain plagioclase feldspar instead of quartz. This distinction may be impossible to make in the hand specimen.

Difficulties with Intrusive Igneous Rocks

In trials of this method by selected groups of students, more difficulty was found in identification of the intrusive type of igneous rocks than any other general group. The difficulty may have been due to too much emphasis on the feldspar content of the rock, and too little regarding the other essential constituents. A study of Figure 1 will show that of the coarse-grained igneous rocks, granite is the only kind which contains an appreciable amount of quartz, and that gabbro contains the greatest amount of the dark ferromagnesian minerals (mica, hornblende, and augite) with diorite containing the next greatest amount. Consequently, if the rock is hard, with visible, interlocking grains of approximately the same size, and contains an appreciable amount of quartz, it probably is a granite. On the other hand, if the rock has

[5] *A Handbook of Rocks*, by J. F. Kemp; 6th edition, revised by F. F. Grout; D. Van Nostrand Co. Inc., New York; 1942.

Preliminary Classification

Group I.—Glassy, wholly or partly.
Group II.—Not glassy; dull or stony; homogeneous; so fine-grained that grains cannot be recognized.
Group III.—Distinctly granular.
Group IV.—Distinctly foliated; no effervescence with acid.
Group V.—Clearly fragmental in composition; rounded or angular pieces or grains cemented together.

GROUP I.—GLASSY ROCKS

1. Glassy luster; hard; conchoidal fracture; colorless to white or smoky gray; generally brittle. *Quartz.*
2. Solid glass; may have spherical inclusions; brilliant vitreous luster; generally black. *Obsidian.*
3. Cellular or frothy glass. *Pumice.*

GROUP II.—DULL OR STONY, VERY FINE-GRAINED ROCKS

SUBGROUP II A.—Not scratched by fingernail, but readily scratched with knife.

1. Particles almost imperceptible; dull luster; homogeneous; clay odor; little if any effervescence with acid; laminated structure; breaks into flakes. *Shale.*
2. Little if any clay odor; brisk effervescence with acid. *Limestone.*
3. Little if any clay odor; brisk effervescence with acid only when rock is powdered or acid is heated. *Dolomite.*
4. Soapy or greasy feel; translucent on thin edges; green to black; no effervescence. *Serpentinite.*

SUBGROUP II B.—Not scratched with the knife or scratched only with difficulty; no effervescence with acid.

1. Light to gray color; clay odor possible; may have a banded flow structure. *Felsite.*
2. Very hard; pale colors to black; no clay odor; conchoidal fracture; waxy or horny appearance. *Chert.* If dark gray to black, *Flint.*
3. Heavy; dark color; may have cellular structure; may contain small cavities filled with crystalline minerals. *Basalt.*

GROUP III.—GRANULAR ROCKS

SUBGROUP III A.—Easily scratched with the knife.

1. Brisk effervescence with acid. *Limestone* or *Marble.*
2. Brisk effervesence only with warm acid, or with powdered rock. *Dolomitic marble.*

SUBGROUP III B.—Hard; not scratched with knife or scratched with difficulty; grains of approximately equal size.

1. Mainly quartz and feldspar; usually light colored, sometimes pinkish. *Granite.*
2. Mainly feldspar; little quartz (less than 5 per cent); light colors of nearly white to light gray or pink. *Syenite.*
3. Feldspar and a dark ferromagnesian mineral.
   (a) Major constituent feldspar; rock of medium color. *Diorite.*
   (b) Ferromagnesian mineral equal to or in excess of feldspar; rock of dark color.
      (1) Grains just large enough to be recognized by the unaided eye. *Diabase.*
      (2) Coarse-grained rock. *Gabbro.*
4. Mainly ferromagnesian minerals; generally dark green to black.
   (a) Predominant olivine with pyroxene or hornblende. *Peridotite.*
   (b) Predominant augite. *Pyroxenite.*
   (c) Predominant hornblende. *Hornblendite.*

GROUP III.—Continued

5. Mainly quartz.
   (a) Fracture around grains. *Sandstone.*
   (b) Fracture through all or through an appreciable percentage of grains. *Quartzite.*

SUBGROUP III C.—Hard; not scratched with knife or scratched with difficulty; large distinct crystals in finer groundmass.

1. Crystals of feldspar and quartz with some of a ferromagnesian mineral (generally biotite) in a light-colored groundmass (of feldspar and quartz). *Granite porphyry.*
2. Crystals of feldspar and usually a ferromagnesian mineral in a light-colored groundmass (of feldspar). *Syenite porphyry.*
3. Crystals of ferromagnesian minerals, or of striated feldspar, or both, in a medium-colored groundmass (of feldspar and ferromagnesian minerals). *Diorite porphyry.*
4. Crystals of quartz, or feldspar, or both, generally with a ferromagnesian mineral, in a predominant, fine-grained groundmass of light color. *Felsite porphyry.*
5. Crystals of feldspar, or of a ferromagnesian mineral, or both, in a fine-grained, dark or black, heavy groundmass. *Basalt porphyry.*

GROUP IV.—FOLIATED ROCKS

1. Medium to coarse grain; roughly foliated. *Gneiss.*
2. More finely grained and foliated. *Schist.*
   (a) Consists mainly or largely of mica with some quartz. *Mica schist.*
   (b) Medium green to black; consists mostly of a felted or matted mass of small, bladed or needle-like crystals arranged in one general direction. *Hornblende schist or amphibolite.*
   (c) Glassy or silky luster on foliation surfaces; splits readily into thin pieces. *Sericite schist.*
   (d) Soft, greasy feel; marks cloth; easily scratched with fingernail; whitish to light gray, or green. *Talc schist.*
   (e) Smooth feel; soft; glimmering luster; green to dark green. *Chlorite schist.*
3. Very fine grain; splits easily into thin slabs; usually dark gray, green, or black. *Slate.*

GROUP V.—FRAGMENTAL

1. Rounded pebbles embedded in some type of a cementing medium. *Conglomerate.*
2. Angular fragments embedded in a cementing medium. *Breccia.*
3. Fragments of volcanic (fine-grained or glassy) rocks embedded in compacted volcanic ash. *Volcanic tuff* or *Volcanic breccia.*
4. Quartz grains, rounded or angular, cemented together. *Sandstone.*
5. Quartz and feldspar grains cemented together to resemble the appearance of granite. *Arkose* (feldspathic sandstone).

the same characteristics as given above, but contains little if any quartz, it can be named by reference to the ferromagnesian mineral content as indicated by the color of the rock. A rock of light color may be a syenite, one of medium color a diorite, and one of dark color a gabbro.

Attention should be given to the transition of rock by insensible stages from one kind to another. Granites will grade into syenites, and syenites into diorites, for instance; or a coarse-grained rock will grade into a fine-grained rock of the same mineralogical composition. Two samples of rock from the same deposit may be sufficiently different to warrant different names. Consequently, the identification of the hand specimen by the method given here does have some limitations. However, a careful study of the sample, following the method outlined, should permit the user to name the rock with a relatively small margin of error.

Highway Definitions—Part II

Approved by A.A.S.H.O.
February 3, 1950

Additions to "Types of Highways"*

Divided Highway

A highway with separated roadways for traffic in opposite directions.

Belt Highway

An arterial highway for carrying traffic partially or entirely around an urban area or portion thereof. (Also called circumferential highway.)

Radial Highway

An arterial highway leading to or from an urban center.

Frontage Street or Road

A local street or road auxiliary to and located on the side of an arterial highway for service to abutting property and adjacent areas and for control of access.

Toll Road, Bridge, or Tunnel

A highway, bridge, or tunnel open to traffic only upon payment of a direct toll or fee.

Cul-de-sac Street

A local street open at one end only and with special provision for turning around.

Dead-end Street

A local street open at one end only without special provision for turning around.

* Highway Definitions, Part I, "Types of Highways," was adopted by the Association on June 25, 1949. The approved policy was published in *American Highways*, Vol. 28, No. 4, October, 1949.

Elements of the Cross Section

Roadway

(General) The portion of a highway, including shoulders, for vehicular use. A divided highway has two or more roadways.

(In construction specifications) The portion of a highway within limits of construction.

Roadbed

The graded portion of a highway, usually considered as the area between the intersections of top and side slopes, upon which the base course, surface course, shoulders and median are constructed.

Subgrade

The portion of the roadbed prepared as a foundation for the base or surface course.

Median

The portion of a divided highway separating the traveled ways for traffic in opposite directions.

Traveled Way

The portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

Shoulder

The portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles, for emergency use, and for lateral support of base and surface courses.

Roadside

A general term denoting the area adjoining the outer edge of the roadway. Extensive areas between the roadways of a divided highway may also be considered roadside.

Traffic Lane

The portion of the traveled way for the movement of a single line of vehicles.

Auxiliary Lane

The portion of the roadway adjoining the traveled way for parking, speed-change, or for other purposes supplementary to through traffic movement.

Parking Lane

An auxiliary lane primarily for the parking of vehicles.

Speed-change Lane

An auxiliary lane, including tapered areas, primarily for the acceleration or deceleration of vehicles entering or leaving the through traffic lanes.

Median Lane

A speed-change lane within the median to accommodate left-turning vehicles.

Outer Separation

The portion of an arterial highway between the traveled ways of a roadway for through traffic and a frontage street or road.

Developing Public Demand for Good Roads[1]

By C. H. SELLS

Executive Director
New York Good Roads Association
Albany, N. Y.

THE highway facility deficit of this nation is in excess of 41 billion dollars! This startling revelation was divulged by a joint congressional committee last Saturday. This amazing condition was likewise reported in the November issue of "Fortune" magazine when they said the roads of this country, after the expenditure of all the war-time created state and local surpluses, were now up to the condition they should have been in 1933.

Seventeen years behind time? Seventeen years out-of-date! And this in the face of the most amazing growth in highway transportation that the nation has ever seen. And also in the face of an economic need such as never has existed. Never before in history, has this nation been so highway dependent as it now is.

People take their roads for granted—they fail to realize their dependence on roads. In order to visualize your dependency on roads just imagine, if you can, that when you wake up tomorrow morning every road in the country will have disappeared. As you walk out on the front porch you will find that the milk bottle is missing. The newspaper is not there. The mail does not come. You can't send your children to school. You can't go to work. The butcher does not come; the baker doesn't come. Nothing happens and there you are, unable to do a thing. You can't even get a doctor if your wife is sick.

There is no facet of the economic life of the people which is not road dependent. Agriculture, manufacturing, commerce, education, recreation, labor, the rural areas, the urban areas—all are dependent for their existence and prosperity on roads. The doctor, the lawyer, the merchant, the candlestick-maker, the baker, the butcher, the teacher—there is nobody in any trade or activity that is not road dependent. You can't even get to the cemetery without going over a road.

[1] Presented at the 33rd Annual Convention of the National Crushed Stone Association, The Stevens, Chicago, Illinois, January 30-February 1, 1950.

How would the farmer get his produce to market if it were not for roads? Where would the manufacturer get his raw materials? How would the city dweller be able to eat garden fresh vegetables if it were not for roads?

These are a few incidental side-lights which are seldom remembered when you think of roads. Eighty per cent of the rubber, seventy-five per cent of the plate glass and over fifty per cent of the malleable iron produced in this nation are consumed by the vehicles which travel on roads. Over 1.5 million people are employed in selling and servicing these vehicles and over 600,000 persons maintain their families by building and maintaining roads. Vacation travellers alone contribute over 9.5 billion dollars to our national economy each year. Nine hundred thousand people are engaged in the manufacture of motor vehicles and over 100,000 in the production of the gasoline to operate them.

The joint committee of our Congress has estimated that almost 42.7 billion man-hours of employment are involved in the modernization program our roads need. This same committee stated that over 5 million Americans spent all or part of their working hours in 1948 driving 7 million trucks over 74 billion miles on our roads. And that all vehicles are traveling over 400 billion miles annually. And all these figures are spiralling upwards!

Statistics are boring but when figures like these just quoted appear in a congressional report, it is time to wake up and take stock of your course.

In thinking of a road program a hasty thought envisions a group of highway engineers and officials surrounded by surveys, records, models, blue prints and specifications. The same hasty thought pictures contractors with all types of interesting equipment boring into the face of nature and doing a face-lifting job with the road cosmetics produced by our mills, mines, factories and quarries. But there is another much more important group than either of these. That group supplies the need, the use and the money—the reason and the means. They are our own people—our workers—our farmers, lawyers, bankers, fathers, mothers, children, our butchers, and our candlestick makers. Without them there

would be no road program—no use for the highway engineer and no need for the road contractor.

The highway engineers are banded together and organized to better understand and fulfill their duties and obligations. They are equipped with experience, training, and the knowledge of their calling. The contractors and material producers are organized in trade and industrial associations and are equipped with brains, brawn and machinery to meet the tasks assigned them. When contractors advocate the need for expanded and continuing road construction programs, they are called selfish. When engineers point out the deficiencies of a road system and present recommendations for its correction they are cast in the unromantic role of "just doing their duty."

Thus we find the two essential groups of the road production cycle powerless and helpless because of an apathetic and lethargic public who take their roads for granted and who fail to realize their complete and absolute dependence on the free and unrestricted circulation of traffic from home to office, from farm to market, from mine to mill, from factory to store, from work to pleasure and from beginning to end.

In an article in a recent issue of "American Highways," Ike Ashburn, Executive Vice President of the Texas Good Roads Association, asks the following questions—

Do the people of your state take roads for granted?

Do hungry hands try to reach into your state income from road user revenues and divert money away from road construction and maintenance operations?

Is traffic congestion resulting from overcrowded highways?

Does your state highway department need civic leadership to assist in the proper development of your road program?

Do you need a public spirited and well informed citizen's organization to run interference for your department in its legislative program and problems?

I think the answer to those questions is a resounding "Yes" in every state in the union.

The American Association of State Highway Officials must also think "Yes" because at their last convention they adopted resolutions calling upon every state to organize a good roads association.

This is an age of organizations. Everybody is organized from acrobats to zoo-keepers. People used to organize in town meetings to discuss their needs and resolve the way to attain them. But in this age of specialties the town meetings have become conventions where particular ideas and plans for specialized endeavors are developed and promulgated—So why shouldn't there be an organization of all types and callings of people 90 per cent of whom are dependent on road transportation for their very existence.

Such an organization can determine the extent of their dependence and their need; can value the benefits they will receive; can fix their ability to pay and can produce the support to fulfill their needs. Such an organization can take its place among other organizations and see to it that their needs receive such proportionate governmental attention and support as their economic welfare demands when blended with the needs and demands for other governmental activities. Such an organization can scrape the mildew off the plans of the highway engineer and support his efforts to develop the nation's economy. Such an organization can insure to the contractor a continuing, stabilized road construction program with steady employment and confident expectation of development of increasing economies. Such an organization can secure for the people of any locality or region a system of road transportation adequate and up-to-date, constructed within the limits of their ability to pay and at the same time maintain adequately other necessary functions of government.

And so we are beginning to find a mighty chant reverberating across the nation. Men and women everywhere are joining their voices in a demand for good roads. Awakening from their years of road-lethargy, the people are telling the powers-that-be that road improvements are a MUST on legislative and fiscal programs of all units of government.

Through organization, the once feeble pleas of the individual citizen are now blended together, magnified a thousand-fold and are being heard and heeded. The instrumentality through which this is being accomplished is the resurgence of the good roads movement which, fifty years ago, led to the first real road construction programs the nation ever knew.

From coast to coast and from border to border individual state good roads associations are militantly taking up the cudgels for their members, the people, in an effort to restore road systems to a point of adequacy and efficiency. Sixteen such groups, ranging from the granddaddy of them all, the fifty-year-old Washington State Good Roads Association, to the youngest, the New York Good Roads Association,

which one Boston newspaper calls "an infant with adult ideas," are on the move. Another similar group is about to be formed in the midwest. But most significant of all is the fact that popular demand in other states may result in formation of additional like associations.

A recent survey conducted by the New York Good Roads Association disclosed the existence of good roads associations in Arizona, Connecticut, Illinois, Iowa, Maine, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New York, North Dakota, Oregon, Rhode Island, Texas and Washington. In addition, Massachusetts has a semi-official good roads group, Colorado has a good roads association which is temporarily inactive, Florida had a temporary good roads association last year and steps are being taken toward the formation of a South Dakota Good Roads Association.

On top of this there are, in such states as California, Idaho, New Mexico, Pennsylvania and possibly others, local groups which are fighting for the procurement of good roads in their respective areas. Meanwhile some of those states which listed themselves as lacking good roads associations indicated a wish that they could report to the contrary.

A study of the data submitted by or about the 16 active good roads associations reveals a general unanimity of purpose, of organization, of philosophy and of action. There are some variances, of course, but in general each association is made up of the average citizens and is striving to convince government that road development is one of its constant and continuing functions and is entitled to a fair share of public funds. Each is seeking to procure for the people good, adequate, efficient roads through expanded and accelerated programs of road improvement by all levels of government.

This, of course, can be accomplished only through united effort. That is why the good roads associations are seeking to enroll the largest possible number of regular members in recognition of the fact that the larger the membership, the more powerful will be their respective and collective voices.

In seeking to bring about the desired goal of good roads, practically all of the good roads associations adhere strictly to the principle that there must be no interference with any public official whose duty it is to build and maintain roads. Rather they are seeking to provide such officials with the necessary funds with which to perform the vast road improvement program they know must be accomplished before the people have the kind of roads they want and need.

Though some charge higher dues, most of the active associations are offering regular memberships at a dollar a year thus offering what the New York Association calls "A Holler For a Dollar." In addition, the various organizations have other types of memberships. Sustaining memberships are welcomed from individuals, companies, corporations, associations, and others who believe that good roads are needed and who wish to contribute funds.

In the matter of procurement of funds with which road builders may do their work there is a diversity of opinion based on individual state needs. Endorsement of legislation or constitutional amendments to preserve for road improvements all or nearly all revenues collected in the form of gasoline taxes and motor vehicle registration fees has been high on the agenda of some groups. Others have worked for increased gas taxes and license fees with the proviso that revenues so obtained would be used for local road improvements. Others have had to battle forces which would revise existing fiscal legislation to the disadvantage of the roads. Still others seek to obtain adequate appropriations within existing fiscal procedures of their respective states. But regardless of the *modus operandi* each good roads association is doing all in its power to make certain that budget makers and legislators, whether they be state, county, city, town or village, do not look upon road improvement programs as government's stepchildren and feed only crumbs while other agencies and functions get the cake.

With each good roads association constantly on the alert, telling the story of roads and their importance to all who will listen; with each good roads association member actively supporting the movement through the recruitment of new members, the goal of good roads everywhere will soon be in sight. And as those states which have active good roads associations get those good roads there is no doubt that the present resurgence of the good roads movement will spread into other states until there is a live, fighting good roads association in each of the 48 states.

During this long period of starvation on our road system we have seen many other activities of government grow and expand and we have seen budgets increased to accommodate this expansion. We have also seen new activities of government created and we have seen new items in the budgets for the main-

tenance of these new facilities. This condition must be all right because the public seems to want it and has not protested its creation. But the day has come when we must consider our economic dependency on roads and the necessity of government to provide for that dependency.

We are not interested in how big a tax dollar is but we are interested in establishing a plan that in each and every tax dollar, small or large, there be a piece of pie devoted to the restoration of road services and that piece of pie should be big enough to supply the proportionate value in our economic life of roads as related to the other necessary functions of government. As our ability to pay taxes is limited, and as that tax dollar is small, there will be a small amount for roads. But that will be all we can afford to pay. If, however, the tax dollar is large, the amount for roads will be proportionately larger but roads will get proportionate recognition with other branches of government, dependent upon our ability to pay, and that is the plan I would like to see established.

Taxes are not the all inclusive cost of roads. Thomas H. MacDonald has said that it costs more to use poor roads than it does to build good ones. This thought was very well exemplified by a newspaper article which appeared recently in the northern part of New Jersey. It was a headline proclaiming in large letters the opening of a new highway through Bergen County to New York. Describing the nature of the highway the article stated that the new highway would save to each and every user 20 minutes a day each way to and from New York. I was interested in this statement and on getting out my pad and pencil I figured what this meant in dollars. Assuming a man's time worth one cent a minute, (and that is less than the amount that Harry Truman says is legal), for each 1,000 people using this highway there are enough pennies saved to pay for the construction of an additional mile of that highway each year. That highway is destined to carry 12,000 people. Consequently, that 20 minutes saved at one cent a minute would build 12 more miles of that highway each and every year.

The economic loss of the people translated into dollars from needless accidents, delays, congestion, property stagnation, broken springs, increased insurance rates, tire destruction, and many other things add up for each and every one to a sum of money which is staggering—but each and everyone must value that in his own way. There is no longer any place for lethargy or apathy regarding the problems we face on roads.

Gentlemen—you have honored my Association and me by allowing me to be with you and I wish to record my deep appreciation. As we go forward to a better way of living believe me always to be good-roadly yours.

Effect of Heavy Loads on Pavement To Be Studied

THE Highway Research Board announced today that plans have been completed for a large-scale test of concrete pavement under concentrated truck traffic using single axle loading of 18,000 and 22,400 lb. per axle and corresponding tandem axle loadings of 32,000 and 44,800 lb. The relative effects of different axle loads will be tested on parallel lanes of the concrete test road. The trucks will operate at an average frequency of one truck per minute on a 24-hr. per day, 7-day per week schedule.

This project has been arranged cooperatively by the states of Connecticut, Delaware, Illinois, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, Virginia, and Wisconsin, and the Bureau of Public Roads, Department of Commerce. Several other states are expected to join the group. The project is to be administered and conducted by the Highway Research Board and will be identified as Road Test One-MD.

A 1.1-mile section of U. S. Route 301 in Southern Maryland has been set aside by the State Roads Commission of Maryland for these tests. This road consists of two 12-ft. lanes of mesh reinforced concrete pavement laid on a good granular subgrade. Each lane is 9-7-9 in. in cross section.

The 1.1-mile section of road will be divided into two sections. In one section, single rear axle trucks loaded to 18,000-lb. axle load will run back and forth over one lane and trucks loaded to 22,400-lb. axle load will run back and forth the same number of times in the parallel lane. The other half-mile section will be tested in the same way with trucks equipped with tandem axles loaded to 32,000 lb. in one lane and 44,800 lb. in the other. In addition to detailed observations of visible effects of the traffic on the pavement, measurements of surface elevations, stresses, and deflections under wheel loads, subgrade condition, and concrete quality will be made.

Crushed Stone Stabilized Bases[1]

By A. T. GOLDBECK

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THE crushed stone stabilized base, which may temporarily serve also as a wearing surface, is one of the flexible road types as distinguished from the rigid type made of concrete. It is axiomatic in the flexible road type that it must have sufficient thickness to spread the wheel loads of the traffic so that the pressure which reaches the underlying subgrade will never exceed its bearing capacity. When that happens the road fails and it is not long before the stone in the surface gets churned up with the subgrade material and its subsequent value as a load carrying material is almost totally lost.

When traffic is light and the subgrade is hard, an inch or two of granular surfacing will carry the load, but in the spring of the year after freezing weather, when the ice in the soil is melting and the "frost is coming out of the ground," the bearing value of the subgrade becomes very low and is totally inadequate for resisting the wheel load pressures reaching it through a thin layer of metal. Almost the sole function of the stone surfacing is to spread the wheel loads over a big enough area of the subgrade to reduce the unit pressure, the pressure in pounds per square inch, to a figure which does not exceed the bearing values of the soil in its softened condition. The stone layer must be thick enough to accomplish that purpose.

Some years ago it was not uncommon to build traffic-bound roads by the application of 500 to 1000 tons per mile which gave a compacted thickness of about one to two inches. This was very beneficial, and on excellent granular subgrades was even adequate, but when any such thickness is used nowadays with our more intense traffic having heavy wheel loads, it is not enough to carry the traffic. When such inadequate surfaces are covered with a bituminous wearing surface, they may seem to be excellent surfaces for a time, but let the subgrade soften and they become a complete failure. As a matter of fact, the bituminous surface which prevented evaporation may have aided failure by causing capillary water to accumulate in the subgrade and stone surfacing.

It now seems to be the better part of wisdom to build up an ample thickness rapidly before the soft subgrade season arrives. This building up process is done in successive layers from windrowed material, each layer being adequately compacted before the following layer is applied. By timing the process so that the required thickness will be attained before the spring thaw, no material will be lost in the mud and the base will be in excellent load supporting condition for any surface treatment desired.

Perhaps it will be appropriate to review briefly some of the details which seem essential in the construction of the granular base course or traffic-bound type of road. It is assumed that the preliminary work has been done and that the right of way, alignment, grade, sight distances, and drainage have been provided for and that it is next desired to develop an all-weather surface of sufficient thickness to carry the traffic at the lowest possible cost.

Important Considerations

In former years the traffic-bound road was considered to be primarily a surfacing. It was an all-weather road, but it pot-holed, became dusty, and required constant maintenance by dragging methods. Furthermore, there was always a great loss of metal from the road surface and this became expensive to replace. The more modern idea is to build up the base of granular material, let it function for a year or two to allow the weak spots to show up and be repaired, so that a uniformly strong base would result, which may then be surface treated or otherwise be given a surface of bituminous materials.

The fundamental principles of traffic-bound construction are simple, but there is a difference in the properties of aggregates which require different methods of construction. This difference is in the natural cementing properties. Some types of aggregates, notably the limestones, compact readily, and cement themselves into a firm stable base while others do not bind very readily. The engineer will have to use his judgment and experience to determine which type of material he is using. Two types of construction will be described—one for aggregates

[1] Presented at the 7th Annual Meeting of the Kentucky Crushed Stone Association, The Seelbach Hotel, Louisville, Kentucky, March 25, 1950.

without cementing properties, and the other for aggregates with natural cementing properties.

The following is reported by our Field Engineer, J. E. Gray, as a result of a special study of traffic-bound roads:

Aggregate Without Natural Cementing Properties

"While, in general, little attention is paid to the soil characteristics of the subgrade, the existing road should be inspected for soils that have a tendency to heave and for locations of poor drainage. All heaving soils should be removed to below the frost line and replaced with suitable granular material. The subgrade should then be brought to a firm, uniform cross-section with a crown of 0 to 1/2 in. per ft. A flat cross-section or a low crown is used with sandy subgrades and a higher crown with clay subgrades.

"A method of construction that has been satisfactory is to spread the aggregate upon the prepared subgrade to a loose depth of 6 in. for the full width of the road. Then the top 4 in. of aggregate is bladed off the road into two windrows on the shoulders and the road is opened to traffic. As soon as the first 2 in. of aggregate is well bound, another 2-in. layer is bladed upon the road from the material stockpiled in the windrows. When this second layer is consolidated, the final 2 in. is spread and compacted by traffic. The result is a continuous building up of a full 6-in. course.

"A gradation specification for the aggregate which has been used with good results is as follows:

"Total per cent passing	1 in.	100
	3/4 in.	95-100
	1/2 in.	65-90
	3/8 in.	35-65
	No. 4	0-15

"The binding of the aggregate with the subgrade soil takes place for the most part during the period following a rain when the soil is moist and somewhat plastic. When the subgrade is hard and dry, obviously, no binding of aggregate or building-up of compacted thickness can take place, so careful, continuous maintenance is essential to provide sufficient aggregate when the subgrade is dry. In other words, with the subgrade moist, up to about 2 in. of loose aggregate should be on the road; if the subgrade is dry and hard, only a floating cover of about 1/2-in. thickness should be maintained.

Aggregate With Natural Cementing Properties

"The natural cementing portion of any aggregate is that passing the 200-mesh sieve. Therefore, road metal having natural cementing properties for this type of construction should be a crusher-run product including all of the dust of fracture. Even then, supplemental fines are often needed. These additional fines are generally created by the grinding action of traffic or they may be applied where needed.

"A gradation specification for crushed stone that has given satisfactory results and is economical to produce is as follows:

"Total per cent passing	1 in.	100
	1/2 in.	60-90
	No. 4	40-60
	No. 16	20-40
	No. 200	5-15

[*Author's Note:* It is interesting at this point to note that the above gradation limits encompass points lying on Professor A. N. Talbot's maximum gradation curves, $P = \sqrt[3]{\frac{d}{D}}$ and $P = \sqrt{\frac{d}{D}}$ The value P is the total per cent passing the sieve opening d and D is the maximum size of sieve opening. The second formula results in more fine material than the first and is close to the ideal gradation for materials which cement well.]

"The construction procedure is to spread the stone on the prepared subgrade to the required thickness either directly from trucks or through a spreader box. The thickness varies from 4 to 10 in. depending upon the intensity of traffic. Usually, trucks haul over the spread stone so that it is compacted to such a degree that the surface is not objectionable to normal traffic. If the application is heavy and the trucks do not compact it sufficiently, the excess loose material is bladed into windrows on the shoulder to be spread upon the road as the aggregate in place becomes consolidated. Again, proper maintenance is essential to building up a firm, stable, smooth-riding surface.

Maintenance

"Since proper maintenance in traffic bound construction is so important, a review of the fundamentals may be in order. Continual surface maintenance with a drag or blade maintainer is necessary to (a) encourage traffic to use the entire road surface, (b) to distribute the aggregate so that it can be bound, and (c) to prevent ruts and corrugations. A

light, 'floating cover' of aggregate should be on the road at all times. However, especially in dry weather, too heavy a cover is conducive to skidding. It is well established that an aggregate of 3/4-in. maximum size can be bladed easily without tearing the underlying, compacted surface. Blading is most effective when done immediately after a rain when the surface is moist. Also, the better practice in blading is to work completely across the road; that is, commence on the right side and go to the left and on the subsequent operation, begin at the left side and work to the right. This is preferred to the old method of blading from each side to the center, thus leaving a wedge of loose aggregate that produces a false crown and is avoided by traffic.

"The maintenance of a proper crown is most important. If the road has fairly level stretches with too flat a cross-section, all slight surface depressions will hold water. Then, under the action of traffic, the fines are soon forced into suspension and are washed away, leaving coarse aggregate without any binder. When dry, traffic soon throws out the loose aggregate causing a pothole. A 1/2 to 5/8 in. per ft. crown should be maintained at all times.

"If potholes should develop, they should be removed by local scarifying and the addition of material similar to that in the body of the road.

Conclusions

"Since all weak spots in a traffic bound road are corrected through proper maintenance, it becomes an ideal base, if of adequate thickness, for a bituminous surfacing of whatever type the intensity of traffic warrants. Construction of this type is a good method for developing a satisfactory base, but it is essential that sufficient aggregate of the proper gradation be placed on the road initially to do the job expeditiously."

Low Cost Road Construction in Knox County, Tennessee

A very informative and interesting paper was presented at the annual meeting of the American Road Builders Association in Cincinnati recently by T. D. Williams, County Engineer of Knox County, Tennessee, on "The Use of Calcium Chloride in Crushed Stone Stabilized Bases." I think enough of a portion of that paper to quote it directly. Mr. Williams states:

"The average road that we are stabilizing and surfacing is an old macadam road where stone has been added periodically and often spasmodically over any number of years, perhaps as high as thirty or forty. It is impossible to determine how many cubic yards of stone have been added to the roadway in this manner, but I am sure it is many, many times that now found in evidence. Undoubtedly the majority of this material was rolled into the ditches, ground up and blown away as dust, pushed far into a wet subgrade, or in some other manner found its way out of the macadam surface. Our borings on this type road show that in the usual case we can depend upon only two inches of existing material that can be used in the future base. If this material is of uniform depth, adequate width and well enough stabilized, the next lift of base material is placed directly upon it. Otherwise it is necessary to scarify the existing macadam, add material if necessary, and reshape to proper depth, width, and crown before rolling and subsequently adding the final lift.

"We have experimented with several types of bases using a variety of different aggregate gradations in order to determine that best suited for our high-type low-cost county road. Although our experiments have not been extensive in any sense of the word, they have proven in our own minds that the type base recently adopted is by far the best and most economical method of solving our problem. As a result of our experience, we have adopted the following as our specifications on graded aggregate used as the total base mix:

Sieve No.	Per Cent Passing: Specifications	Per Cent Passing: Used
1 in.	100	100
3/4 in.	80-100	95
3/8 in.	50-90	77
No. 4	36-65	61
No. 10	22-50	38
No. 40	15-30	16
No. 200	5-15	5

The last column in the above table gives a gradation being used at present. To many of you, it may appear that there is too little material passing the No. 200 sieve. We too believe this to be true but it is realized that if construction costs are to be kept at a minimum, local materials must be used. We find that by using our own materials, we can combine approximately 60 per cent of crusher run stone (stone not screened) and 40 per cent limestone dust (obtained when the crusher screens are installed to produce oil stone) and arrive at the above noted gradation. To arrive at a perhaps more suitable gradation, addi-

tional binder soil would have to be obtained and we find this to be impractical in our location. Our soils are extremely heavy clays that are difficult to pulverize and blade uniformly into the combined aggregates. If lighter soils were obtainable, perhaps a better graded aggregate could be used. By constructing bases composed of limestone aggregate and limestone dust, with no additional metallic or soil binder material, we have a much greater latitude in aggregate control, mixing, and rolling. In other words, a person of reasonable experience in stabilizing these materials can by 'rule of thumb' methods, such as feel and sight, quite accurately determine if the aggregates are properly graded, mixed, and cured in preparation for final laying and rolling.

"Our roads vary tremendously in traffic volume. Depending upon location, the traffic count varies from less than 100 vehicles per day to over 5,000. The majority of roads included in our improvement program carry a traffic volume requiring the base to be constructed to a 6-in. compacted thickness. When less than 4-in. additional compacted thickness is required to give an adequate depth, it may be constructed in one lift. If over 4 in. are required, it should be compacted in layers not exceeding 3 in. in order to insure a well compacted thickness.

"Construction procedure of the base may be outlined as follows:

"1. Coarse aggregates are spread on the roadway—preferably by mechanical means, such as tail gate spreaders or spreader boxes. This operation should be rigidly controlled by means of placing a checker on the roadway to accurately control the dumping distance. This material unless evenly distributed should be leveled by means of a patrol grader.

"2. Limestone dust is added on top of the coarse aggregate in a similar manner.

"3. After a minimum of 1/2 mile and a maximum of 1 mile of aggregate is thus placed, calcium chloride is added at the uniform rate of 1 lb. per sq. yd. per 3 in. of lift.

"4. The material is then bladed by standard methods from side to side with a patrol grader until it is adequately and uniformly mixed. Water must be added at the beginning and, if necessary, throughout the operation. Experience alone can teach one the correct amount of water to be added.

"5. After the material is properly mixed, it should be windrowed and left to cure. This curing, depending upon temperature and weather conditions, normally requires two days. Mixing operations can proceed at another section of the project during this curing period.

"6. After curing is complete, the material should again be bladed to insure that no segregation has taken place, and then leveled to the proper grade and crown. Rollers, preferably 8-10 ton three wheel, can then complete the operation.

"7. Once the operation is completed, the base should be allowed to again cure before adding the second lift, or in the event this second lift is not needed, before the surface is primed. Normally, when calcium chloride is used, watering during this curing period is not required. However, it is extremely important to insure against drying out too fast.

"The use of calcium chloride in our bases has been discussed at great lengths in our organization. As stated before, we were trying to arrive at the most economical base and it was doubted at first if sufficient benefits would be derived from the use of calcium chloride to pay for its cost. To satisfy ourselves, we placed several stretches of base using principally the same aggregates, some with and some without calcium chloride. Our findings plainly show that the calcium chloride base is definitely desirable and the most economical in the end."

The author then proceeds to outline the advantages of using calcium chloride which need not concern us at present. Those interested in this phase of the construction can readily obtain a copy of Mr. Williams's paper.

After the base is stabilized and as traffic develops, as it generally does on an improved road, it will soon pay to cover the base with some form of bituminous treatment or penetration macadam or bituminous concrete. Excellent surfaces of all three types are possible and the type selected will be governed by the intensity of traffic.

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These associate members are morally and financially aiding the Association in its efforts to protect and advance the interests of the crushed stone industry. Please give them favorable consideration whenever possible.

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